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Original Research Article

Comparison of the effectiveness of polymer gel dosimeters (Magic and Pagatug) for organ dose calculation in brachytherapy, nuclear medicine and teletherapy

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Abstract

Purpose: *To investigate and compare two polymer gel dosimeters, Magic and Pagatug, as organ dosimeters for 3D measurement of dose distribution in brachytherapy, nuclear medicine and teletherapy.*
Methods: *Magic and Pagatug polymer gels were compared with soft tissue based on irradiation with low energy photons during therapeutic applications. Comparison was simulated using Monte-Carlo-based MCNPX code. ORNL phantom–Female was used to model some vital organs (kidneys, ovaries and uterus). The right kidney was proposed to be the source of irradiation and the two organs were exposed to this irradiation.*
Results: *The effective atomic numbers of soft tissue, Magic and Pagatug were 6.86134, 7.07 and 7.2884, respectively. The results showed that Magic and Pagatug, were comparable to soft tissue with regard to application in nuclear medicine and teletherapy. Differences between gel dosimeters and soft tissue were defined as the dose responses. This difference was < 8.1, < 4 and < 76.8 % for teletherapy, nuclear medicine and brachytherapy, respectively.*
Conclusion: *Due to slight differences between the effective atomic numbers of these polymer gel dosimeters and soft tissue, the polymer gels are not suitable for brachytherapy since the photoelectric interaction is dominant for low energy photons, and the interaction relates to Z4. The results demonstrate that the gel dosimeters are best suited for nuclear medicine.*

Keywords: *Magic, Pagatug, Brachytherapy, Nuclear medicine, Teletherapy, Organ dosimetry, Soft tissue*

INTRODUCTION

There are several dosimetry techniques used to determine the distribution of radiation dose during radiation treatment. Each dosimeter tool has a set of unique advantages and disadvantages. Gel dosimeters are appropriate dosimeters for determining 3D dose distribution with high spatial resolution unlike conventional dosimeters such as radioactive ionization chambers, TLD cards and radiography films [1,2].

The TLD cards (also called mini ionization chambers) have some drawbacks in measuring very high doses with high dose gradients, due to their finite sizes which permit measurement of the dose only at a single point [1]. Film batches can also offer 3D dose measurements by positioning film in multiple planes but accurate positioning of films in several layers can be a difficult and time-consuming process. Therefore, conventional dosimeters are suitable for clinical brachytherapy [3]. Fricke gel and polymer gel dosimeters are two different dosimeters which can give 3D dose distribution. However, polymer gel dosimeters maintain a high spatial integrity when compared with the Fricke gel dosimeters [4]. There are several different scans in nuclear medicine applications, of which heart scans are the most common. In these scans, the kidneys absorb the highest amount of dose as well as some other critical organs such as ovaries and uterus [5]. For this reason, the source positions are placed in the kidneys in brachytherapy, and the kidneys are radiated in nuclear medicine and teletherapy.

As stated earlier, polymer gels can be used in medical phantoms as valuable tools for determining 3D dose distribution in a medium. Polymer gel dosimeter can replace medical phantom materials as media with features similar to soft tissue. This type of dosimeter can be considered as a suitable option for studying dose distribution in sensitive organs during radiation therapy and nuclear medicine. The dose received in sensitive organs has important role during radiation therapy and nuclear medicine.

Therefore, in the present study, the capabilities of polymer gel dosimeters, Magic and Pagatug as medical phantoms for evaluating absorbed dose of radiation in the ovaries and uterus from the right kidney during brachytherapy, nuclear medicine and teletherapy were investigated.

EXPERIMENTAL

ORNL phantom-Female was chosen for this study. The phantom consisted of 3 materials and 40+ discrete cells that simulate the human body [6]. The radiation sources considered for brachytherapy, nuclear medicine and teletherapy are TC-99m [4], Co-60 [7] and ^{125}I [6], respectively.

Table 1 shows the composition of the Magic and Pagatug polymer gel dosimeters, while Table 2 shows the elemental composition of ORNL phantom-Female.

Table 1: Construction of polymer gel dosimeters, Magic and Pagatug

Material	w_C	w_H	w_N	w_O	w_S	$w_{Cu(ii)}$	ρ(g.cm−3)	ρ_e	Z_{eff}
Magic[8]	0.0751	0.1062	0.0139	0.8021	2.58×10^{-6}	5.08×10^{-6}	1.06	3.51	**7.07**
Pagatug[9]	0.092	0.102	0.034	0.771	-	-	1.0653	3.53	**7.2884**

W_C: percentage weight of carbon in composition; W_H: percentage weight of hydrogen in composition; W_N: percentage weight of nitrogen in composition; W_O: percentage weight of oxygen in composition; W_S: percentage weight of sulphur in composition; W_{Cu}: percentage weight of copper in composition

Table 2: Elemental composition of the tissues for ORNL phantom–Female [11]

	Weight (%)		
Element	***Soft tissue***	***Skeleton***	***Lung***
H	10.454	7.337	10.134
C	22.663	25.475	10.238
N	2.490	3.057	2.866
O	63.525	47.893	75.752
F	0	0.025	0
Na	0.112	0.326	0.184
Mg	0.013	0.112	0.007
Si	0.030	0.002	0.006
P	0.134	5.095	0.080
S	0.204	0.173	0.225
Cl	0.133	0.143	0.266
K	0.208	0.153	0.194
Ca	0.024	10.190	0.009
Fe	0.005	0.008	0.037
Zn	0.003	0.005	0.001
Rb	0.001	0.002	0.001
Sr	0	0.003	0
Zr	0.001	0	0
Pb	0	0.001	0
Density (g/cm^3)	1.04	1.4	0.296
Z_{eff}	6.86134	-	-

Simulation procedure

In this study, MCNPX 2.6.0 was used for the simulations. F4 tallied with DFn, and DEn was used for dose measurement. Figure 1 shows simulated phantom (ORNL phantom–Female) in MCNPX code.

RESULTS

Outputs of simulations were determined for polymer gel dosimeters and soft tissue during brachytherapy, nuclear medicine and teletherapy, and the results are shown in Table 3 and Table 4.

Table 3 shows that the polymer gel dosimeters, Magic and Pagatug, are comparable to soft tissue for use in nuclear medicine and teletherapy. Differences between gel dosimeters and soft tissue were defined as the dose responses. This difference is < 8.1, < 4 and < 76.8 % for teletherapy, nuclear medicine and brachytherapy, respectively.

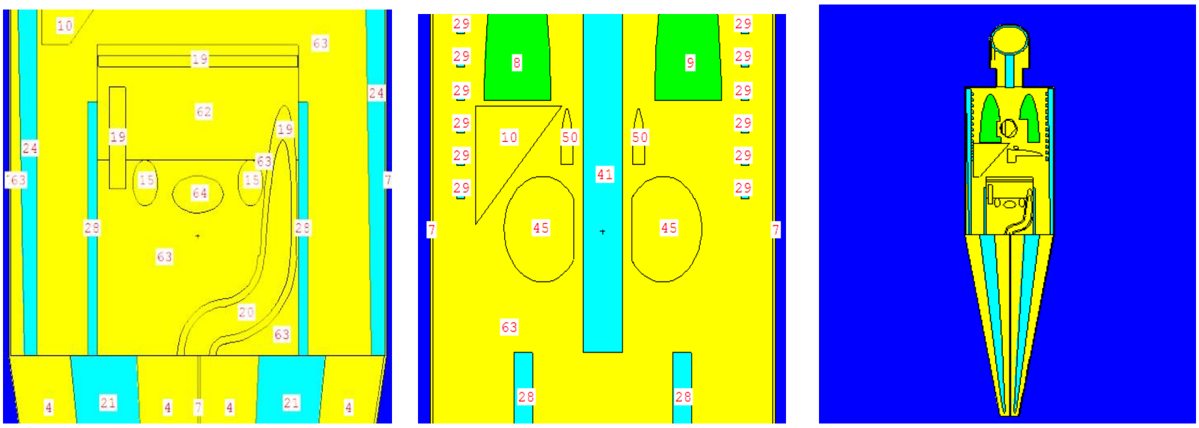

Figure 1: Simulated phantom ORNL phantom–Female (15 Ovaries, 45 Kidneys and 64 Uterus)

Table 3: Output of simulations for polymer gel dosimeters during Brachytherapy, Nuclear medicine and Teletherapy

Type of source	Activity MBq	Source position	Evaluated organ	Dose in evaluated organ rem/h	Error	Type of dosimeter	Density of dosimeter gr/cm^3	Difference with soft tissue %
^{125}I	1110	Right kidney	Ovaries	2.18E-2	0.0260	**Magic**	1.095	68.5
^{125}I	1110	Right kidney	Uterus	1.72E-2	0.0164	**Magic**	1.095	73.3
TC-99m	1110	Right kidney	Ovaries	7.13E-2	0.0111	**Magic**	1.095	3.4
TC-99m	1110	Right kidney	Uterus	6.29E-2	0.0071	**Magic**	1.095	3.1
Co-60	188E+6	100 cm from right kidney	Ovaries	6.94E-7	0.0587	**Magic**	1.095	-8.1
Co-60	188E+6	100 cm from right kidney	Uterus	6.89E-7	0.0404	**Magic**	1.095	-1.4
^{125}I	1110	Right kidney	Ovaries	6.68E-3	0.0388	**Pagatug**	1.0653	67
^{125}I	1110	Right kidney	Uterus	5.57E-3	0.0227	**Pagatug**	1.0653	76.8
TC-99m	1110	Right kidney	Ovaries	6.06E-2	0.0102	**Pagatug**	1.0653	3.9
TC-99m	1110	Right kidney	Uterus	5.30E-2	0.0061	**Pagatug**	1.0653	3.5
Co-60	188E+6	Right kidney	Ovaries	6.33E-7	0.0569	**Pagatug**	1.0653	-8.1
Co-60	188E+6	Right kidney	Uterus	6.30E-7	0.0405	**Pagatug**	1.0653	-1.5

Table 4: Output of simulations for soft tissue during brachytherapy, nuclear medicine and teletherapy

Type of source	activity MBq	Source position	Evaluated organ	Dose in evaluated organ rem/h	Error
Co-60	188E+6	100 cm away from right kidney	Ovaries	6.89E-7	0.0557
Co-60	188E+6	100 cm away from right kidney	Uterus	6.40E-7	0.0401
^{125}I	1110	Right kidney	Ovaries	4.00E-3	0.0228
^{125}I	1110	Right kidney	Uterus	3.15E-3	0.0127
TC-99m	1110	Right kidney	Ovaries	5.83E-2	0.0046
TC-99m	1110	Right kidney	Uterus	5.12E-2	0.0027

Table 5: Comparison between errors (%) of Magic and Pagatug Gel dosimeters

Type of treatment	Max. error in using MAGIC	Max. error in using PAGATUG
Teletherapy	8.1	8.1
Nuclear medicine	3.4	3.9
Brachytherapy	68.5	76.8

The results demonstrate that the gel dosimeters are best suited for nuclear medicine.

Table 6, Table 7 and Table 8 show the ratios of photon interactions for the polymer gel dosimeters and soft tissue during brachytherapy, nuclear medicine and teletherapy. These results show that the dominant interaction in the polymer gel dosimeters and soft tissue for nuclear medicine and teletherapy was Compton

Table 6: Photon with polymer gel dosimeter and soft tissue interactions ratio for Brachytherapy

Brachytherapy					
Pagatug					
Flux(photon)	1.11E-5	**Ovaries**	Flux (photon)	9.23E-6	**Uterus**
Reaction rate	2.15E-6	Incoherent	Reaction rate	1.79E-6	Incoherent
Reaction rate	4.87E-7	Coherent	Reaction rate	4.05E-7	Coherent
Reaction rate	1.36E-6	Photoelectric	Reaction rate	1.14E-6	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	4.00E-6	Total	Reaction rate	3.33E-6	Total
Magic					
Flux (photon)	1.11E-5	**Ovaries**	Flux(photon)	9.09E-6	**Uterus**
Reaction rate	2.15E-6	Incoherent	Reaction rate	1.76E-6	Incoherent
Reaction rate	4.92E-7	Coherent	Reaction rate	3.98E-7	Coherent
Reaction rate	1.40E-6	Photoelectric	Reaction rate	1.13E-6	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	4.05E-6	Total	Reaction rate	3.28E-6	Total
		Soft Tissue			
Flux (photon)	6.84E-6	**Ovaries**	Flux(photon)	5.45E-6	**Uterus**
Reaction rate	1.16E-6	Incoherent	Reaction rate	9.28E-7	Incoherent
Reaction rate	3.15E-7	Coherent	Reaction rate	2.48E-7	Coherent
Reaction rate	1.11E-6	Photoelectric	Reaction rate	8.51E-7	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	2.59E-6	Total	Reaction rate	2.03E-6	Total

Table 7: Photon with polymer gel dosimeter and soft tissue interactions ratio for nuclear medicine

Nuclear medicine					
Pagatug					
Flux(photon)	1.78E-4	**Ovaries**	Flux (photon)	1.55E-4	**Uterus**
Reaction rate	3.19E-5	Incoherent	Reaction rate	2.78E-5	Incoherent
Reaction rate	2.19E-6	Coherent	Reaction rate	1.97E-6	Coherent
Reaction rate	2.96E-6	Photoelectric	Reaction rate	2.70E-6	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	3.71E-5	Total	Reaction rate	3.25E-5	Total
Magic					
Flux (photon)	1.77E-4	**Ovaries**	Flux (photon)	1.55E-4	**Uterus**
Reaction rate	3.18E-5	Incoherent	Reaction rate	2.77E-5	Incoherent
Reaction rate	2.18E-6	Coherent	Reaction rate	1.96E-6	Coherent
Reaction rate	2.94E-6	Photoelectric	Reaction rate	2.67E-6	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	3.69E-5	Total	Reaction rate	3.24E-5	Total
		Soft Tissue			
Flux (photon)	1.74E-4	**Ovaries**	Flux (photon)	1.53E-4	**Uterus**
Reaction rate	2.74E-5	Incoherent	Reaction rate	2.41E-5	Incoherent
Reaction rate	2.02E-6	Coherent	Reaction rate	1.81E-6	Coherent
Reaction rate	3.12E-6	Photoelectric	Reaction rate	2.82E-6	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	3.26E-5	Total	Reaction rate	2.87E-5	Total

(incoherent) scattering, while in brachytherapy, both Compton (incoherent) and photoelectric were the dominant interactions. The similarity in dominant interactions for the polymer gels and soft tissue shows a good agreement which is of interest for the dosimetry applications.

DISCUSSION

In this study, the capabilities of Magic and Pagatug polymer gel dosimeters for measuring 3D dose distribution during brachytherapy, nuclear medicine and teletherapy were evaluated by MCNPX code, and their dose responses were compared with soft tissue. These polymer gel dosimeters are capable of measuring complex 3D dose distributions with high spatial resolution, unlike other radiation dosimeters such as ionization chambers, TLD and radiographic films. The results showed that the dosimeters were more suitable for use in teletherapy and nuclear medicine when compared as opposed to brachytherapy. In brachytherapy the two gel

Table 8: Photon with polymer gel dosimeter and soft tissue interactions ratio for teletherapy

Pagatug					
Flux (photon)	9.08E-15	**Ovaries**	Flux(photon)	9.00E-15	**Uterus**
Reaction rate	1.49E-15	Incoherent	Reaction rate	1.49E-15	Incoherent
Reaction rate	6.04E-17	Coherent	Reaction rate	6.74E-17	Coherent
Reaction rate	6.18E-17	Photoelectric	Reaction rate	7.93E-17	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	1.61E-15	Total	Reaction rate	1.63E-15	Total
Magic					
Flux (photon)	9.08E-15	**Ovaries**	Flux(photon)	9.03E-15	**Uterus**
Reaction rate	1.49E-15	Incoherent	Reaction rate	1.49E-15	Incoherent
Reaction rate	6.10E-17	Coherent	Reaction rate	6.77E-17	Coherent
Reaction rate	6.40E-17	Photoelectric	Reaction rate	7.91E-17	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	1.61E-15	Total	Reaction rate	1.64E-15	Total
		Soft tissue			
Flux (photon)	9.81E-15	**Ovaries**	Flux (photon)	9.08E-15	**Uterus**
Reaction rate	1.42E-15	Incoherent	Reaction rate	1.32E-15	Incoherent
Reaction rate	6.68E-17	Coherent	Reaction rate	6.41E-17	Coherent
Reaction rate	8.49E-17	Photoelectric	Reaction rate	9.18E-17	Photoelectric
Reaction rate	0.00	Pair Production	Reaction rate	0.00	Pair Production
Reaction rate	1.58E-15	Total	Reaction rate	1.48E-15	Total

dosimeters had more than 10 percent error, which is not acceptable in brachytherapy. The difference observed between the gel dosimeters and soft tissue is related to incoherent interaction with 48.1 % deviation. In teletherapy, both Magic and Pagatug had similar errors and they were both reliable. Photoelectric interaction is the main cause of difference between polymer gels and soft tissue in teletherapy. In nuclear medicine, Magic has less error when compared to Pagatug, due to differences between their effective atomic numbers. The effective atomic numbers for soft tissue, Pagatug and Magic were 6.86134, 7.2884 and 7.07, respectively.

It is known that photoelectric interaction is dominant for lower energy photons and this interaction relates to atomic number as Z^4 [10]. Since the effective atomic numbers of soft tissue and the gel dosimeters were different, larger errors would occur in lower energy photons. Hence, the dose response measurement error for Pagatug polymer gel was larger than that for Magic polymer gel.

CONCLUSION

The results obtained in this investigation strongly suggest that if low energy sources are required in therapeutic applications, Magic and Pagatug polymer gel dosimeters are acceptable soft tissue equivalent dosimeters.

DECLARATIONS

Conflict of Interest

No conflict of interest associated with this work.

Contribution of Authors

The authors declare that this work was done by the authors named in this article and all liabilities pertaining to claims relating to the content of this article will be borne by them.

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